

Amendments to the Claims:

This listing of claims will replace all prior versions, and listings, of claims in the application:

Listing of Claims:

1.-32. (Canceled)

33. (Currently Amended) ~~A~~The method of claim 50~~useful in three-dimensional pose estimation for use with a single camera mounted to a movable portion of a robot, the method~~further comprising:

capturing a number of images of a calibration object by the camera;

determining a set of intrinsic parameters of the camera from at least one of the number of images of the calibration object captured by the camera; and

determining a set of extrinsic parameters of the camera from at least one of the number of images of the calibration object captured by the camera, the set of extrinsic parameters comprising a camera space-to-training space transformation defining a transformation between a camera space reference frame and a training space reference frame.

34. (Previously Presented) The method of claim 33, further comprising:
positioning the camera with respect to the calibration object.

35. (Previously Presented) The method of claim 34 wherein positioning the camera with respect to the calibration object comprises positioning the camera orthogonally with respect to a ruled template with a number of features, where a known or determinable physical relationship exists between at least some of the features.

36. (Previously Presented) The method of claim 34 wherein positioning the camera with respect to the calibration object comprises positioning the camera with respect to a sample of a type of object the robot will manipulate, the sample having a number of features,

where a known or determinable physical relationship exists between at least some of the features.

37. (Previously Presented) The method of claim 34 wherein capturing a number of images of a calibration object by the camera comprises capturing at least one image at each of a plurality of positions spaced perpendicularly from the calibration object.

38. (Previously Presented) The method of claim 34 wherein capturing a number of images of a calibration object by the camera comprises capturing at least one image at each of a plurality of different orientations with respect to the calibration object.

39. (Previously Presented) The method of claim 33 wherein determining a set of intrinsic parameters of the camera from the at least one of the number of images of the calibration object captured by the camera comprises determining at least one of a focal length, a first order radial lens distortion coefficient, a set of coordinates of a center of a radial lens distortion, or a scale factor indicative of a framegrabber scanline resampling uncertainty.

40. (Previously Presented) The method of claim 33 wherein determining a set of extrinsic parameters of the camera from at least one of the number of images of the calibration object captured by the camera, the set of extrinsic parameters comprising a camera space-to-training space transformation defining a transformation between a camera space reference frame and a training space reference frame comprises determining a respective translation component along three orthogonal axes, and a respective rotation component about the three orthogonal axes.

41. (Previously Presented) The method of claim 33, further comprising:
determining a camera space-to-tool space transformation based at least in part on at least two of the number of images captured by the camera of the calibration object.

42. (Previously Presented) The method of claim 33, further comprising:

determining a camera space-to-tool space transformation based on single one of the number of images captured by the camera of the calibration object and on a number of physical coordinates of at least one feature of the calibration object.

43. (Currently Amended) The method of claim ~~50~~33, further comprising:

capturing an image of a teaching object of a type of object that will be manipulated by the robot;

selecting a number of features from the captured image of the teaching object;

determining a set of object space coordinates for each of the selected features from the captured image of the teaching object; and

44. (Previously Presented) The method of claim 43 wherein selecting a number of features from the captured image of the teaching object comprises selecting six features from the captured image of the teaching object.

45. (Previously Presented) The method of claim 43, further comprising:

determining an object space-to-camera space transformation defining a transformation between an object space reference frame and the camera space reference frame.

46. (Previously Presented) The method of claim 45, further comprising:

determining a position and an orientation of an object frame in the tool frame reference frame based at least in part on the object frame-to-camera space and camera space-to-tool space transformations.

47. (Previously Presented) The method of claim 46, further comprising:

providing the position and orientation of the object frame to the robot; and
training an intended operation path inside the object frame.

48. (Canceled)

49. (Currently Amended) The method of claim ~~50~~48, further comprising:

adjusting a position of the movable portion of the robot if the number of features located in the captured image of the target object is determined to be an insufficient number of features; and

capturing another two-dimensional image of the volume containing the target object before determining the object space-to-camera space transformation for the target object.

50. (Currently Amended) A ~~The~~ method useful in three-dimensional pose estimation for use with a single camera mounted to a movable portion of a robot ~~of claim 48, the method further~~ comprising:

capturing a two-dimensional image of a volume containing a target object; and

locating a number of features in the captured image of the target object; and

determining an object space-to-camera space transformation for the target object based at least in part on a position of at least some of the located features using only the signal captured image and an algorithm that employs a known or determinable physical relationship between at least some of the located features.

51. (Previously Presented) The method of claim 50, further comprising:

determining at least one movement of the robot that orients the camera orthogonally with respect to the target object based at least in part on the object space-to-camera space transformation.

52. (Previously Presented) The method of claim 51, further comprising:

determining a position of the object frame in the tool space reference frame; and
providing an object frame to the robot.

53. (Currently Amended) An apparatus useful in robotics, the apparatus comprising:

a single camera operable to capture at a number of images of a calibration object by the camera;

means for calibrating the camera, by:

determining a set of intrinsic parameters of the camera from at least one of the number of images of the calibration object captured by the camera; and

determining a set of extrinsic parameters of the camera from at least one of the number of images of the calibration object captured by the camera, the set of extrinsic parameters comprising a camera space-to-training space transformation defining a transformation between a camera space reference frame and a training space reference frame; and

means for estimating a pose of a target object, by:

capturing a two-dimensional image of ~~an~~a volume containing a target object; and

locating at least six features in the captured image of the target object; and

determining an object space-to-camera space transformation based at least in part on a position of at least some of the located features in solely the captured image using an algorithm that employs a known or determinable physical relationship between at least some of the located features.

54. (Previously Presented) The apparatus of claim 53, further comprising:

means for training, comprising:

capturing an image of a teaching object of a type of object that will be manipulated by the robot;

selecting a number of features from the captured image of the teaching object;

determining a set of object space coordinates for each of the selected features from the captured image of the teaching object; and

determining an object space-to-camera space transformation defining a transformation between an object space reference frame and the camera space reference frame.

55. (Previously Presented) The apparatus of claim 54 wherein the means for calibrating, the means for estimating a pose, and the means for training comprises at least one programmed computer.

56. (Previously Presented) The apparatus of claim 54 wherein the means for calibrating, the means for estimating a pose, and the means for training comprises at least one computer-readable medium storing instructions operating at least one computer.

57. (Previously Presented) The apparatus of claim 53 wherein the pose estimating means estimates the pose of the target object further by:

adjusting a position of the movable portion of the robot if the number of features located in the captured image of the target object is determined to be an insufficient number of features.

58. (Currently Amended) An apparatus useful in robotics, the apparatus comprising:

a single camera operable to capture a number of images of a calibration object by the camera;

means for calibrating the camera, by:

determining a set of intrinsic parameters of the camera from at least one of the number of images of the calibration object captured by the camera; and

determining a set of extrinsic parameters of the camera from at least one of the number of images of the calibration object captured by the camera, the set of extrinsic parameters comprising a camera space-to-training space transformation defining a transformation between a camera space reference frame and a training space reference frame; and

means for estimating a pose of a target object, by:

capturing a two-dimensional image of ~~an~~ a volume containing a target object;~~and~~
locating at least five features in the captured image of the target object;
and
determining an object space-to-camera space transformation based at least in part on a position of at least some of the located features using the captured image without any additional captured images and an algorithm that employs a known or determinable physical relationship between at least some of the located features.

59. (Previously Presented) The apparatus of claim 58 wherein the means for calibrating and the means for estimating a pose comprises at least one programmed computer.

60. (Previously Presented) The apparatus of claim 58 wherein the means for calibrating and the means for estimating a pose comprises at least one computer-readable medium storing instructions operating at least one computer.

61. (Previously Presented) The apparatus of claim 58 wherein the pose estimating means estimates the pose of the target object further by:

adjusting a position of the movable portion of the robot if the number of features located in the captured image of the target object is determined to be an insufficient number of features.